



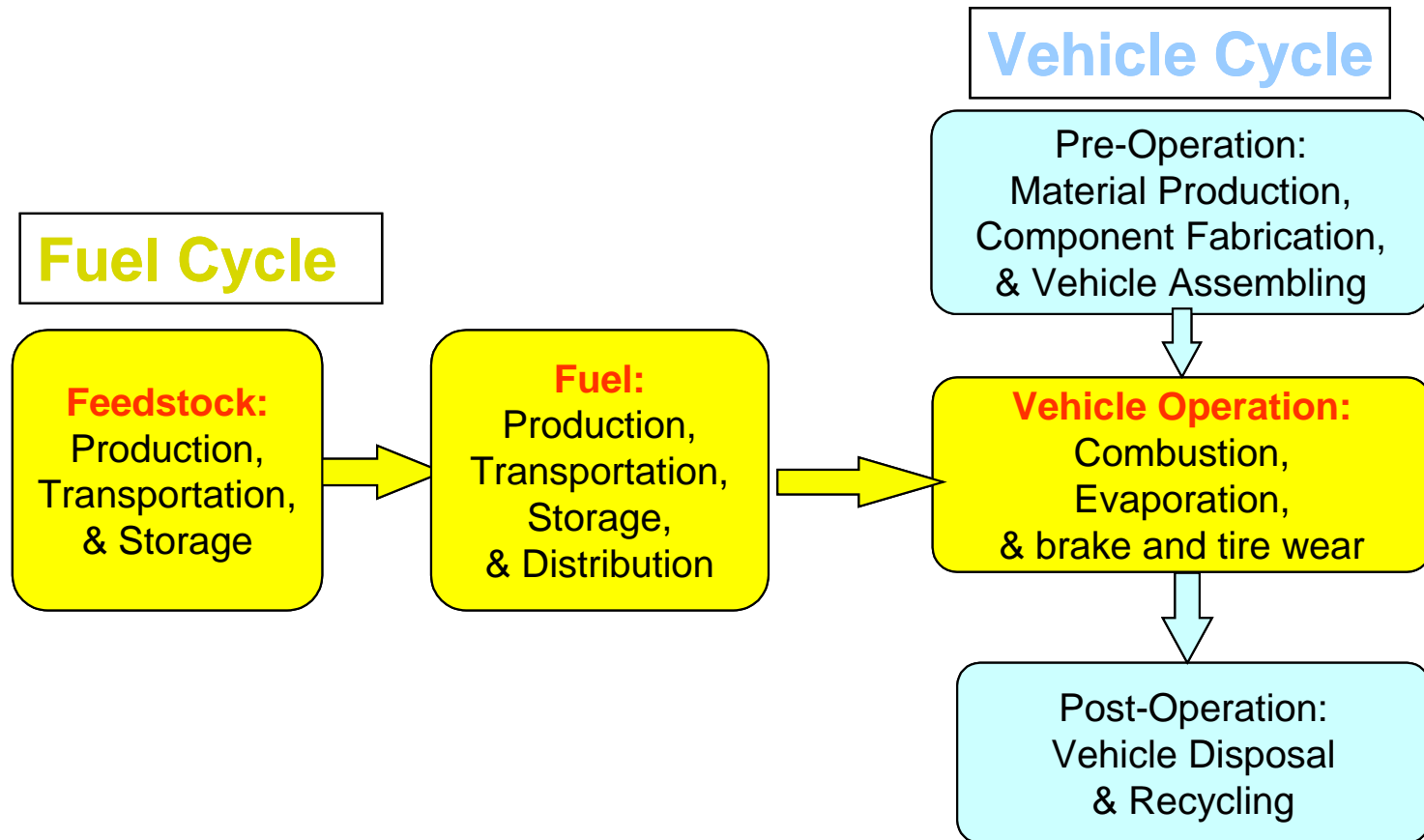
Life-Cycle Analysis of Transportation Fuels and Vehicle Technologies: Development and Use of the GREET Model

Michael Wang
Center for Transportation Research
Argonne National Laboratory

August 2000

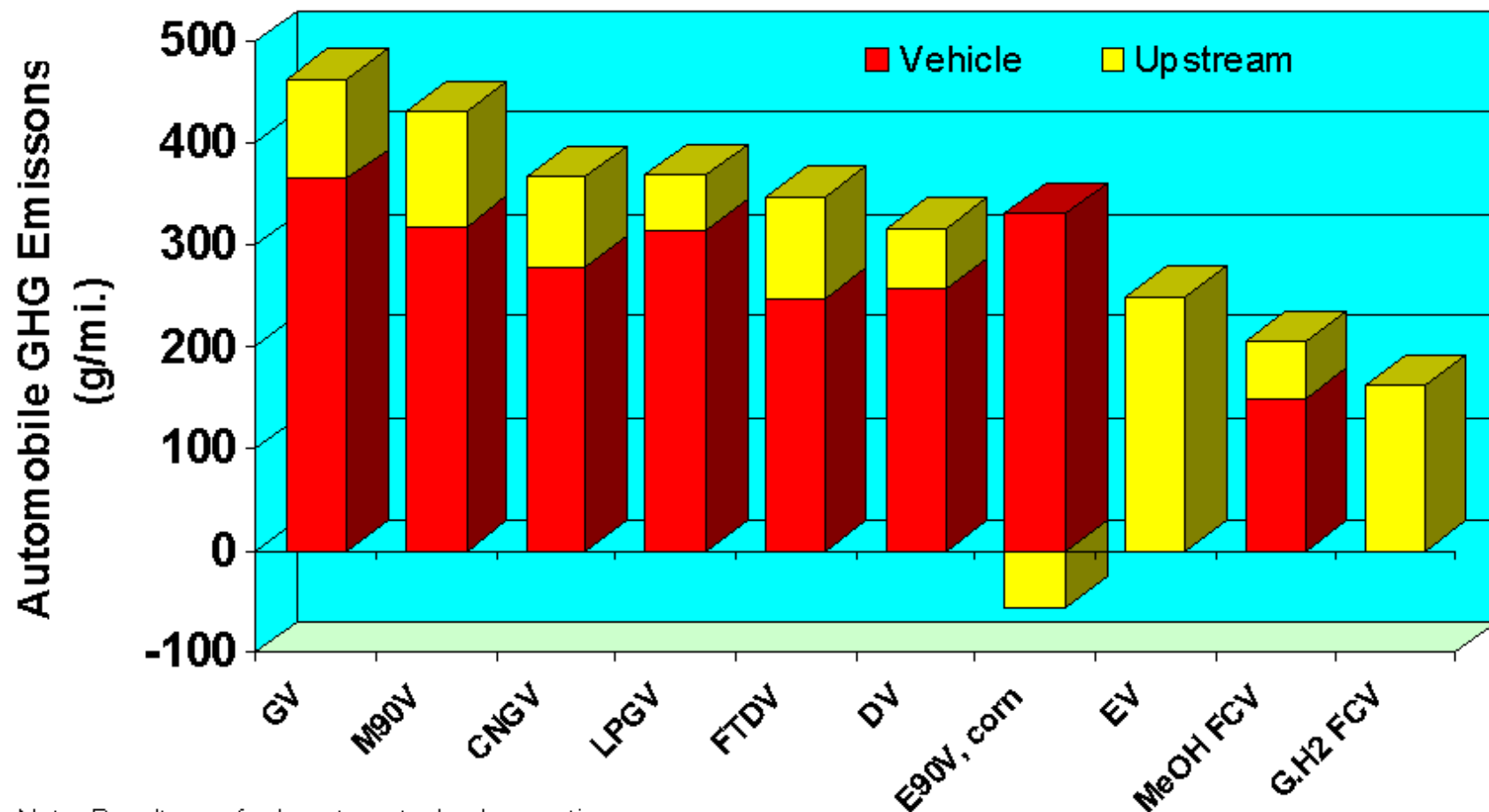


Total Energy Cycle Includes Fuel Cycle and Vehicle Cycle





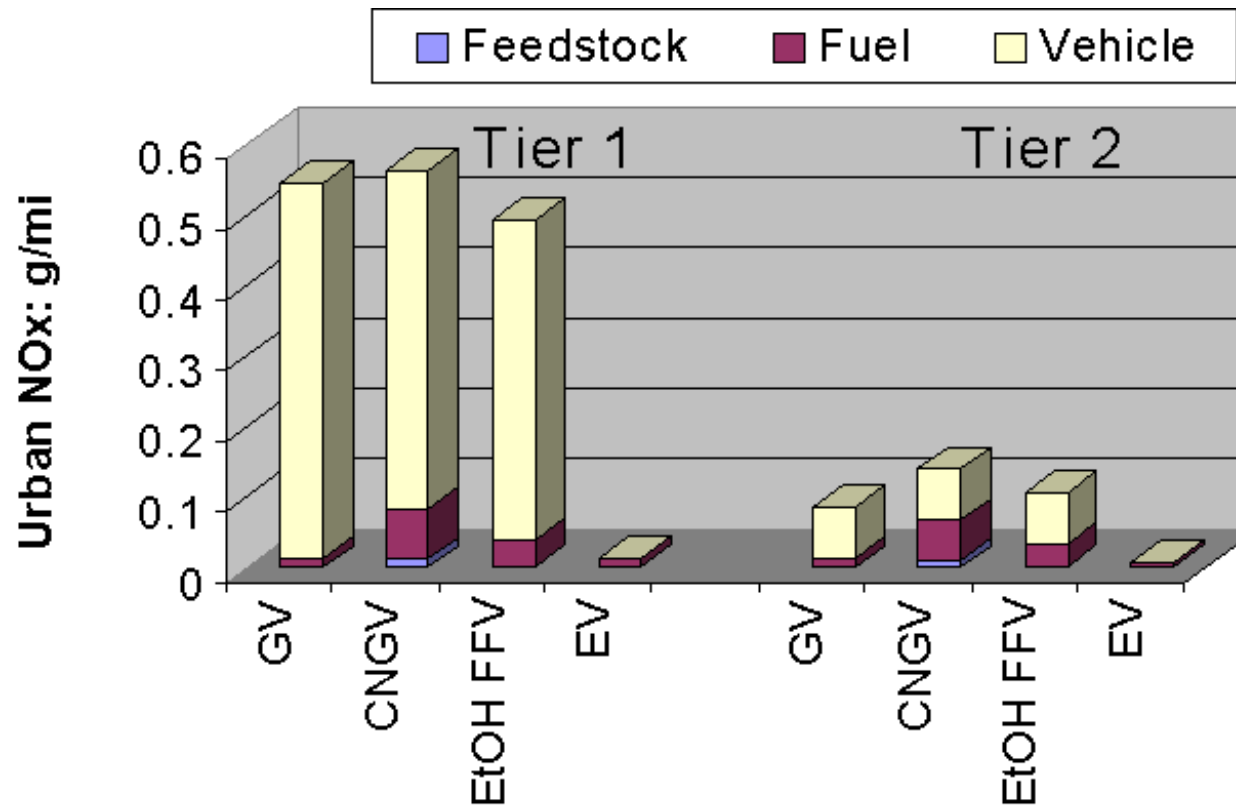
Upstream Emissions Can Make a Difference When Comparing Vehicle/Fuel Systems



Note: Results are for long-term technology options.



As Tailpipe Emissions Will Be Tightened for Future Vehicles, Upstream Emissions Could Become a Major Source





The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model

- **The GREET Model**
 - A total energy cycle model to estimate per-mile energy use and emissions rates
 - First version was developed in 1996
- **GREET Comprises Three Sub-Models**
 - The 1st is a fuel-cycle model for cars and light-duty trucks (the current version is GREET1.5a)
 - The 2nd is a vehicle-cycle model for cars and light-duty trucks (draft, not documented)
 - The 3rd is a fuel-cycle model for classes 2b - 8 trucks (draft, not documented)

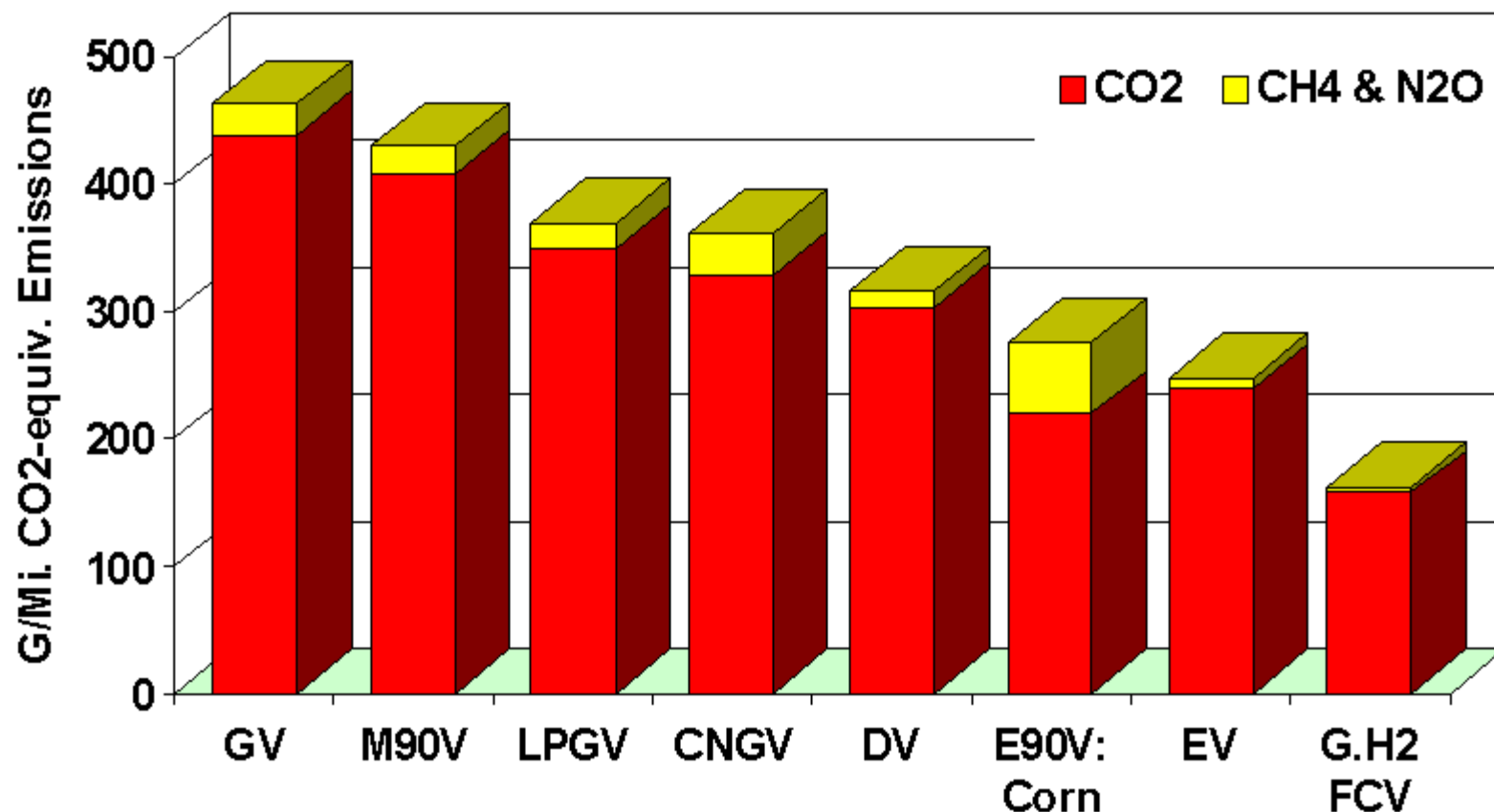


GREET Simulates These Emission and Energy Items

- **Emissions of Greenhouse Gases**
 - CO_2 , CH_4 , and N_2O
 - VOC, CO, and NO_x as optional GHGs
- **Emissions of Five Criteria Pollutants (Total and Urban Separately)**
 - VOC, CO, NO_x , PM_{10} , and SO_x
- **Energy Use**
 - All energy sources
 - Fossil fuels
 - Petroleum



Methane and Nitrous Oxide Emissions from Some Vehicle/Fuel Systems Can Be Significant



Note: 1) Long-term technology options.
2) Global warming potentials of CH4 and N2O are IPCC 100-yr. values.



GREET Users Cover a Range of Industries and Organizations

- **Government Agencies:**

DOE/OTT EPA USDA Various states
Congressional Committees

- **The Auto Industry:**

GM Ford Toyota Honda Nissan

- **The Energy Industry:**

Exxon/Mobil BP Shell Texaco Syntroleum
NG industry Ethanol industry

- **Other Countries:**

Canada Germany France the U.K. Taiwan
Australia China Japan Thailand

- **Others:**

Universities (UC Davis, MIT, Carnegie Mellon U., Harvard, etc.)
Environmental Community (UCS, ACEEE, EESI, etc.)
World Bank
Consulting companies



ANL Has Applied GREET in Several Major Studies in the Past Several Years

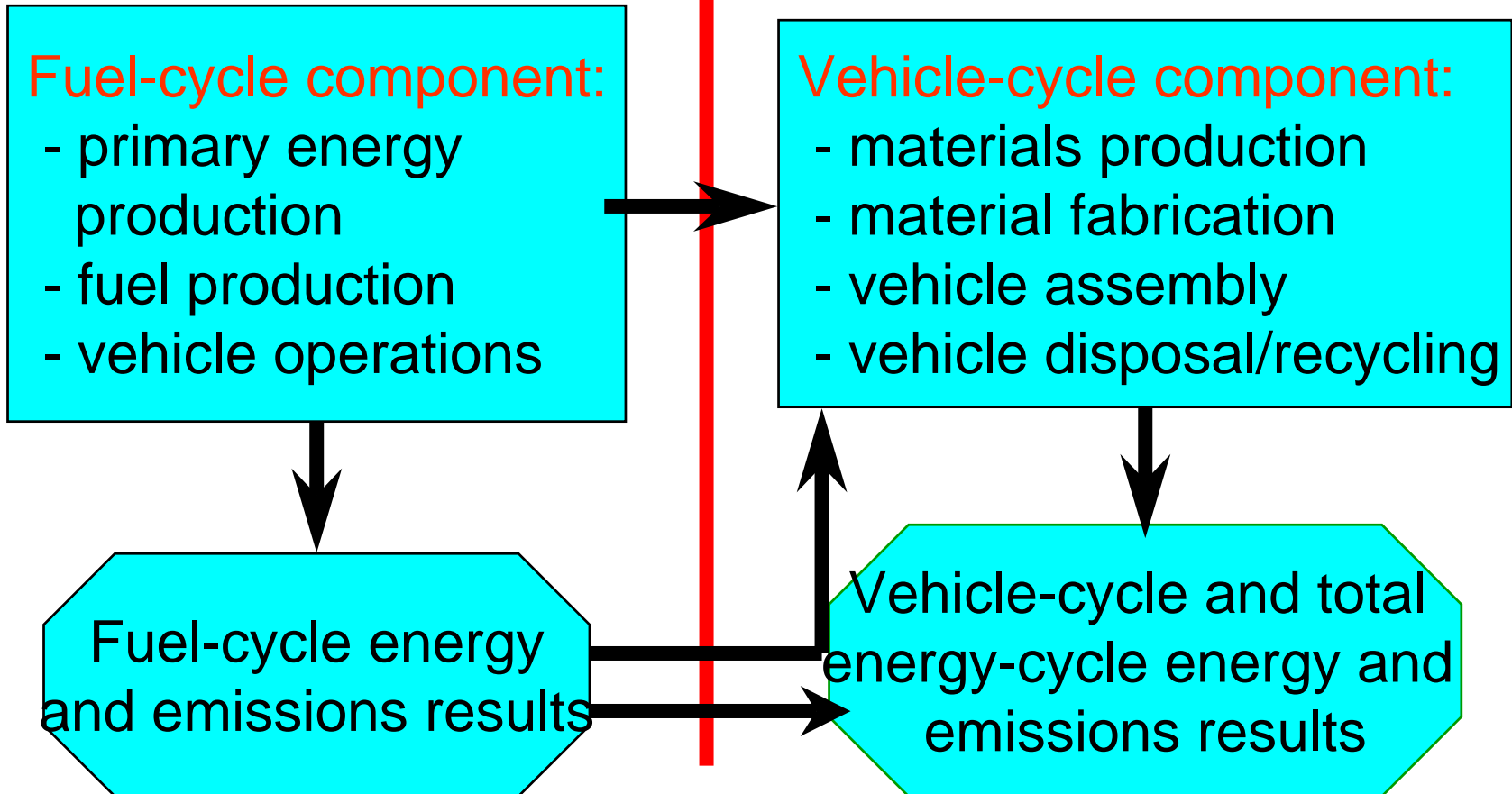
- DOE/OTT has been using GREET in its quality metrics exercise since 1997
- ANL has applied GREET to the PNGV fuels infrastructure project for OTT's OAAT since 1997
- ANL conducted comprehensive studies on corn and biomass ethanol with GREET for State of IL, USDA, EPA, and DOE
- ANL conducted a thorough study with GREET to evaluate fuels produced from natural gas for OTT's OTU
- ANL is currently conducting a study for GM's GAPC to evaluate fuels for fuel-cell and hybrid vehicles



Connections of the Three GREET Sub-models

GREET1.# and GREET3.#

GREET2.#





GREET Series 1 and GREET Series 3 Together Include All Vehicle Classes

Series 1 GREET Model		Series 3 GREET Model	
Vehicle Type	GVWR: lb. ^a	Vehicle Type	GVWR: lb. ^a
Passenger cars	0 – 6,000	Class 2b – 4 trucks	8,501 – 16,000
Class 1 trucks	0 – 6,000	Class 5 - 6 trucks	16,001 – 26,000
Class 2a trucks	6,001 – 8,500	Class 7 trucks	26,001 – 33,000
		Class 8a trucks	33,001 – 60,000
		Class 8b trucks	> 60,000
		School buses	21,000 – 31,000
		Transit and commercial buses	26,001 – 60,000

^a Gross vehicle weight rating.



GREET's Calculation Logic for Upstream Emissions (grams/mmBtu of Fuel Delivered to Vehicle Tanks)

Inputs:

Emission Factors

Combustion Tech. Shares

Energy Efficiencies

Fuel Type Shares

Facility Location Shares

Calculations:

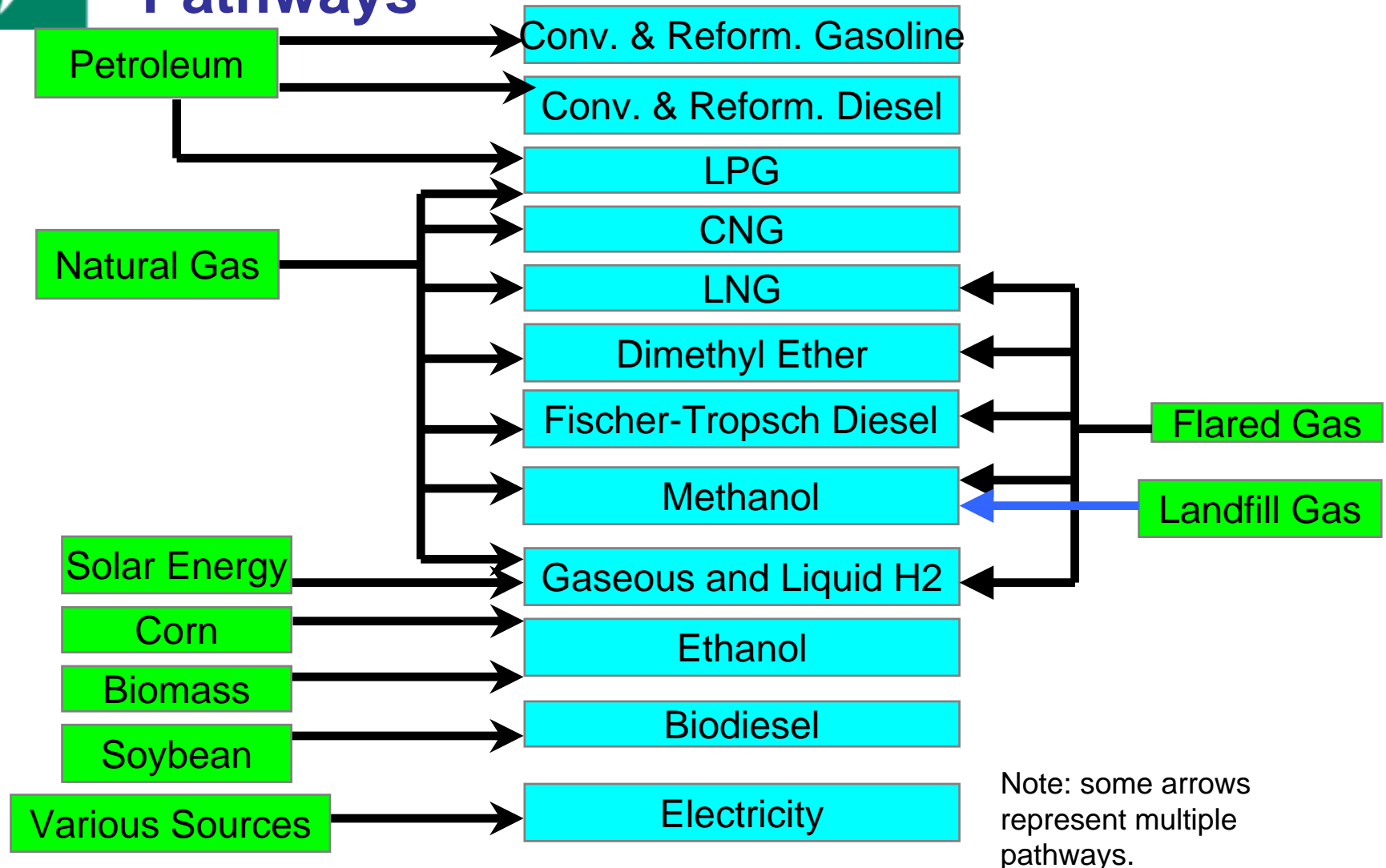
Energy Use by Fuel Type

Total Emissions

Urban Emissions

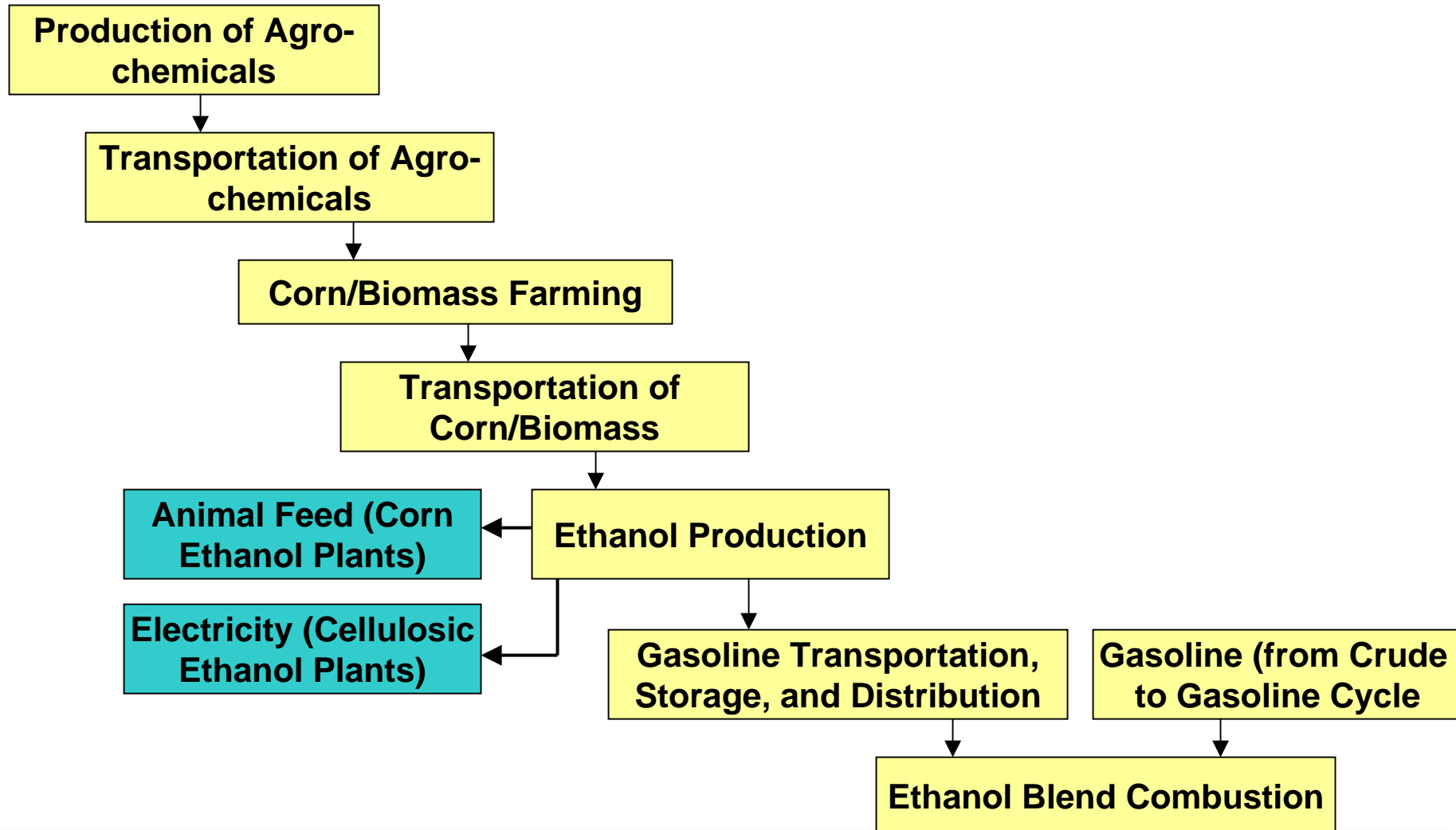


GREET Includes More Than 30 Fuel-Cycle Pathways





Each Fuel-Cycle Pathway in GREET Includes Detailed Activities: Example of Ethanol Cycles





Key Upstream Issues Addressed in GREET: Petroleum Fuels

- Gasoline sulfur content will be reduced to 15-30 ppm by 2006 from the current level of 200-300 ppm
- Diesel sulfur content is proposed to be reduced to 15 ppm from the current level of ~350 ppm
- On the other hand, marginal crude has high sulfur content
- Desulfurization in petroleum refineries increases hydrogen consumption considerably, resulting in high energy use and emissions
- MTBE in reformulated gasoline will be phased out or down nationwide. It is not clear if ethanol, or no oxygenate, will be used



Key Upstream Issues Addressed in GREET: Natural Gas-Based Fuels

- **Gas Reserve**

- Worldwide, the size of conventional gas reserve is about as large as that of crude reserve
- At present, gas consumption is only ~60% of oil consumption

- **CNG**

- An energy efficient way to use gas in transportation
- CNG stations could cause high urban NO_x emissions
- CNG vehicle driving range is limited

- **LNG**

- Allows for cross-ocean transportation
- Production suffers moderate efficiency loss



Key Upstream Issues Addressed in GREET: Natural Gas-Based Fuels (cont.)

- **Methanol**
 - Technology is proven and mature
 - Production suffers efficiency loss and high emissions
 - Is being promoted as a fuel-cell fuel
- **Fischer-Tropsch Diesel**
 - A high-quality diesel engine fuel (low sulfur and aromatics)
 - Able to use the existing diesel fuel distribution infrastructure
 - Production technology is still evolving
 - Production suffers large efficiency loss and emissions
- **Dimethyl Ether**
 - Can be stored in liquid form at moderate pressure (like LPG)
 - A good diesel engine fuel
 - Production suffers efficiency loss and high emissions



Fuels Produced from Flared Gas Achieve Hugh Energy and Emission Benefits

- Worldwide, ~3.8 trillion ft³ of gas (~655 million barrels of oil) is flared each year
- Gas flaring is already restricted in some countries for reducing CO₂ emissions
- Production of liquid fuels from flared gas makes it possible to transport the fuels to user sites
- GREET1.5a simulates production of methanol, dimethyl ether, Fischer-Tropsch diesel, liquefied natural gas, and liquid hydrogen from flared gas
- These pathways achieve huge energy and emission benefits



Three Pathways of Producing H₂ from NG Have Pros and Cons

	NG to G.H ₂ : large central plants	NG to G.H ₂ : R. stations	NG to L.H ₂
Fuel production	Large, efficient	Small, less efficient	Large, but inefficient
H₂ pipelines (expensive)	Yes	No	No
Vehicle driving range	Short	Short	Long
Upstream H₂ storage	Yes (extensive)	Yes (less extensive)	Yes
CO₂ sequestration	Yes	Probably no	Yes

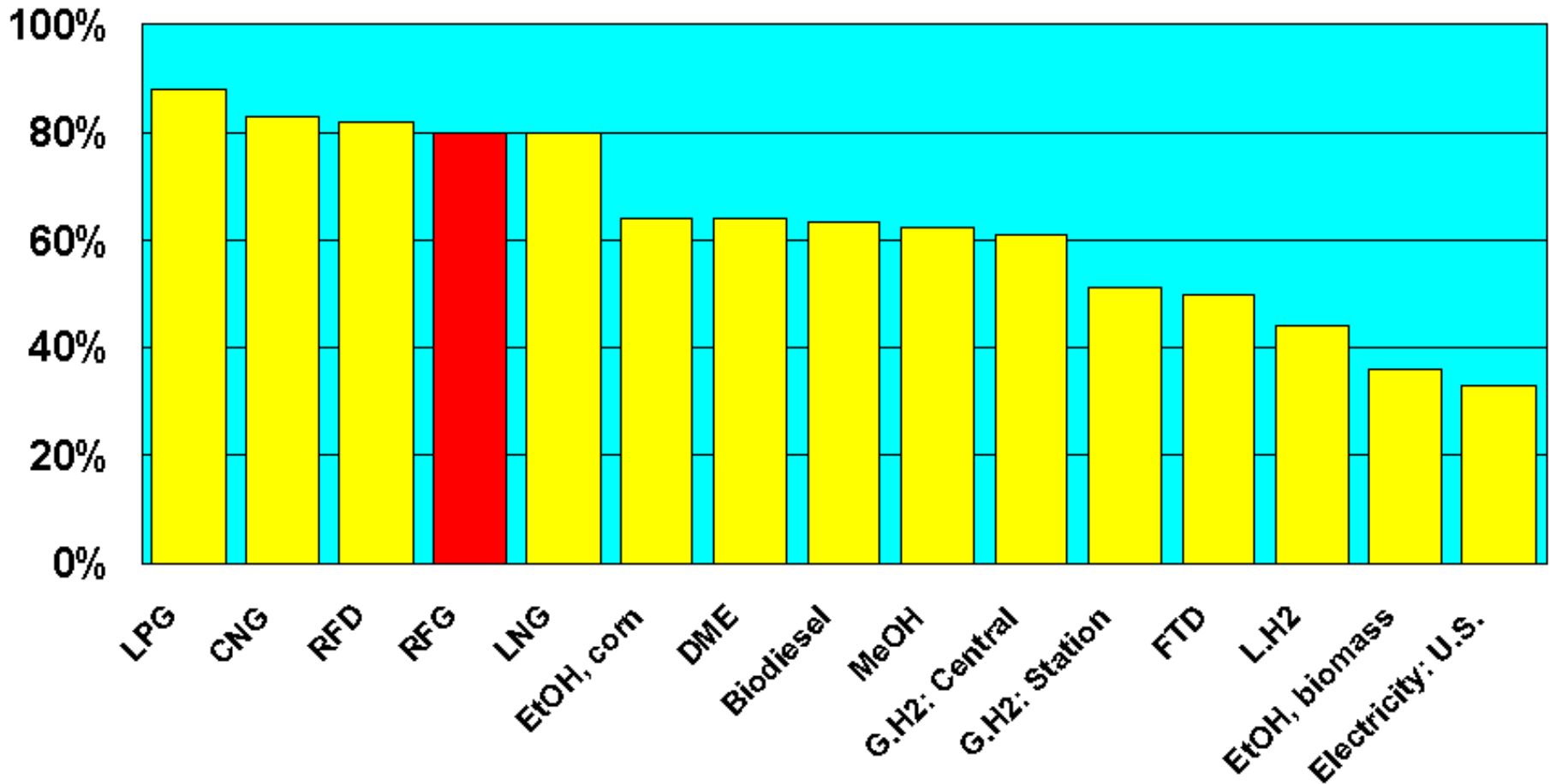


Emissions of Electricity Generation Very Much Depends on Generation Mix

	U.S. Mix	CA Mix	NE U.S. Mix
Coal	53.8%	7.0%	28.2%
Natural gas	14.9%	30.6%	31.6%
Oil	1.0%	0.2%	2.5%
Nuclear	18.0%	14.1%	26.3%
Others	12.3%	48.1%	11.4%



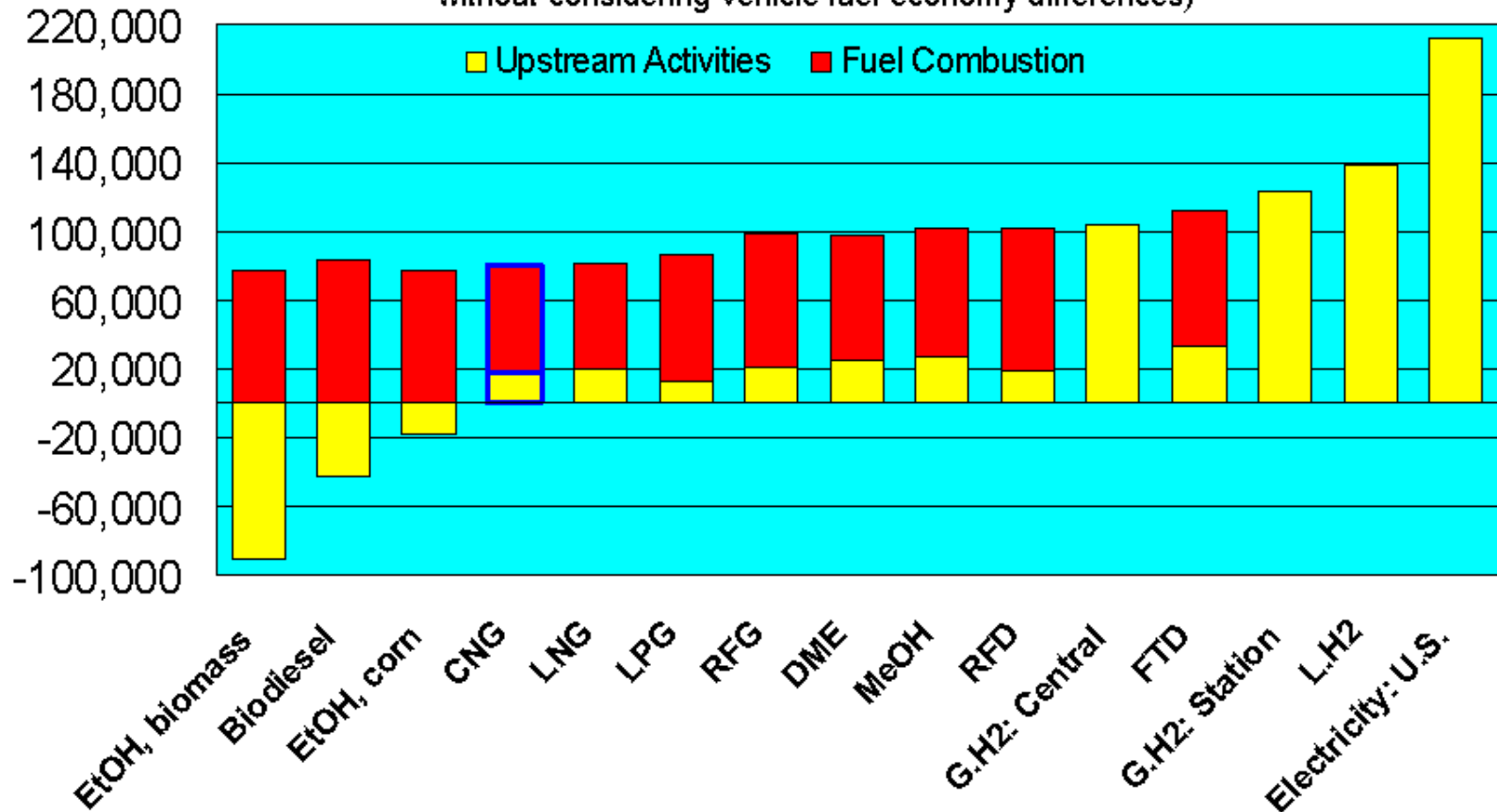
Energy Efficiencies of Upstream Activities (Wells to Tanks)





GHG Emissions of Fuel Production and Combustion: Grams per Million Btu of Fuel

(Results here show GHG emissions effects from fuel switch without considering vehicle fuel economy differences)





Vehicular Emissions Are Estimated with These Steps in GREET

- Emissions of VOC, CO, NO_x, CH₄, and PM₁₀:
 - Baseline gasoline and diesel vehicles:
 - HC, CO, NO_x and CH₄ are estimated with EPA's Mobile5b
 - PM₁₀ is estimated with EPA's Part5
 - Alternative-fueled vehicles:
 - AFV emission change rates relative to GVs or DVs are estimated with testing results or engineering analysis
 - AFV emissions are calculated with AFV emission change rates and baseline GV or DV emissions
- SO_x emissions for each vehicle type are calculated from sulfur contained in fuels
- CO₂ emissions for each vehicle type are estimated from carbon balance]
- N₂O emissions are based on limited testing results



REET1.5a Includes 14 Near-Term Vehicle/Fuel Systems (available now)

Conv. SI Vehicles

- Conv. gasoline, RFG
- CNG: dual-fuel and dedicated
- LPG: dedicated
- MeOH, EtOH: flexible-fueled

SIDI HEVs: RFG

- Grid-independent
- Grid-connected

CIDI Vehicles

- Conv. diesel

CIDI HEVs

- CD, grid-independent

Battery-Powered EVs

- U.S. generation mix
- CA generation mix
- NE U.S. generation mix



REET1.5a Includes 45 Long-Term Vehicle/Fuel Systems (available ~2010)

Conv. SI Vehicles

- RFG
- CNG, LNG, and LPG: dedicated
- MeOH and EtOH: dedicated

SIDI Vehicles

- RFG, MeOH, and EtOH

SI HEVs: Grid-Independent and Grid-Connected

- RFG, MeOH, EtOH (SIDI)
- CNG, LNG, and LPG (SI)

CIDI Vehicles

- RFD, DME, FTD, and biodiesel

CIDI HEVs: Grid-Independent and Grid-Connected

- RFD, DME, FTD, and biodiesel

Battery-Powered EVs

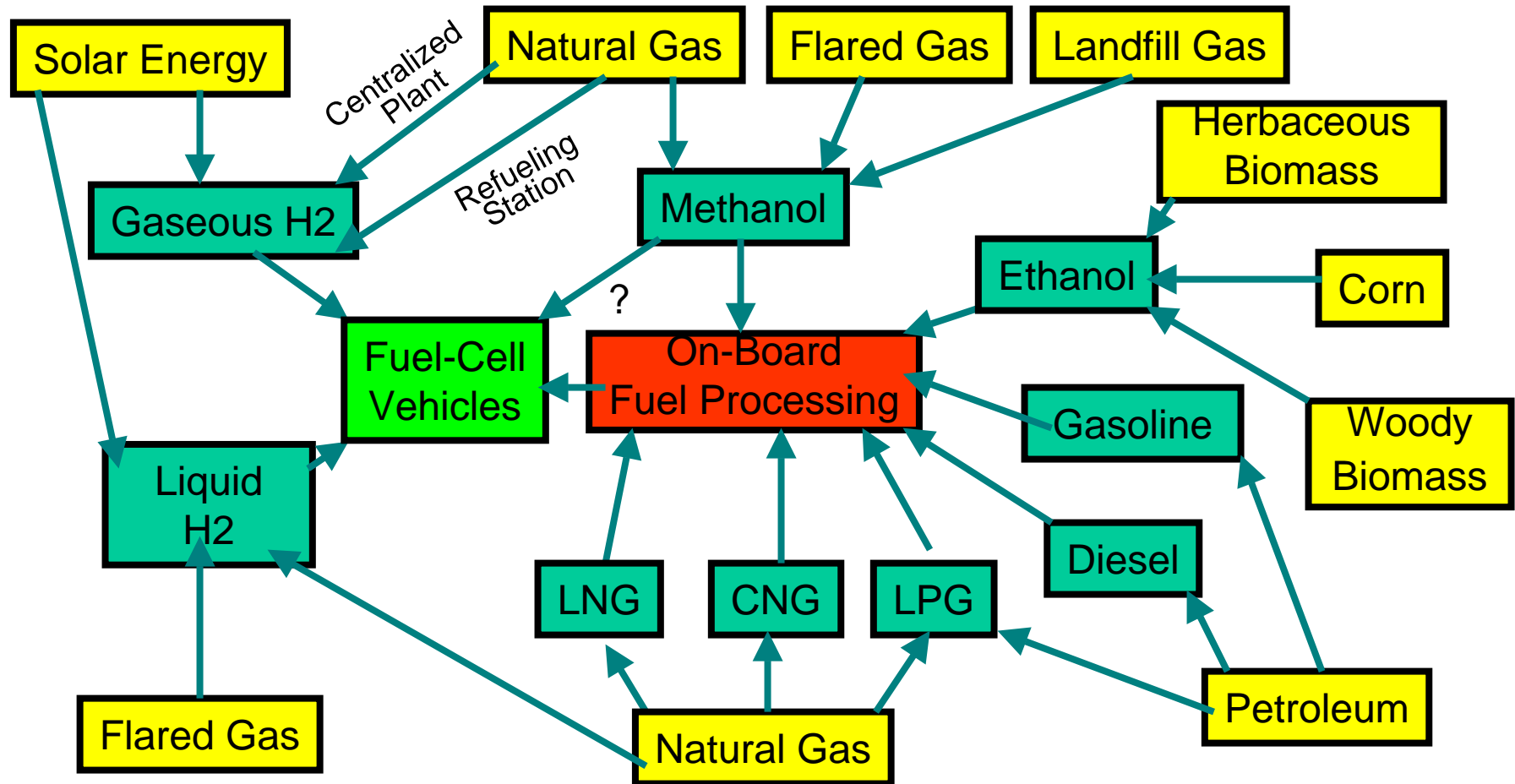
- U.S. generation mix
- CA generation mix
- NE U.S. generation mix

Fuel-Cell Vehicles

- G.H₂, L.H₂, MeOH, RFG, RFD, EtOH, CNG, LNG, and LPG

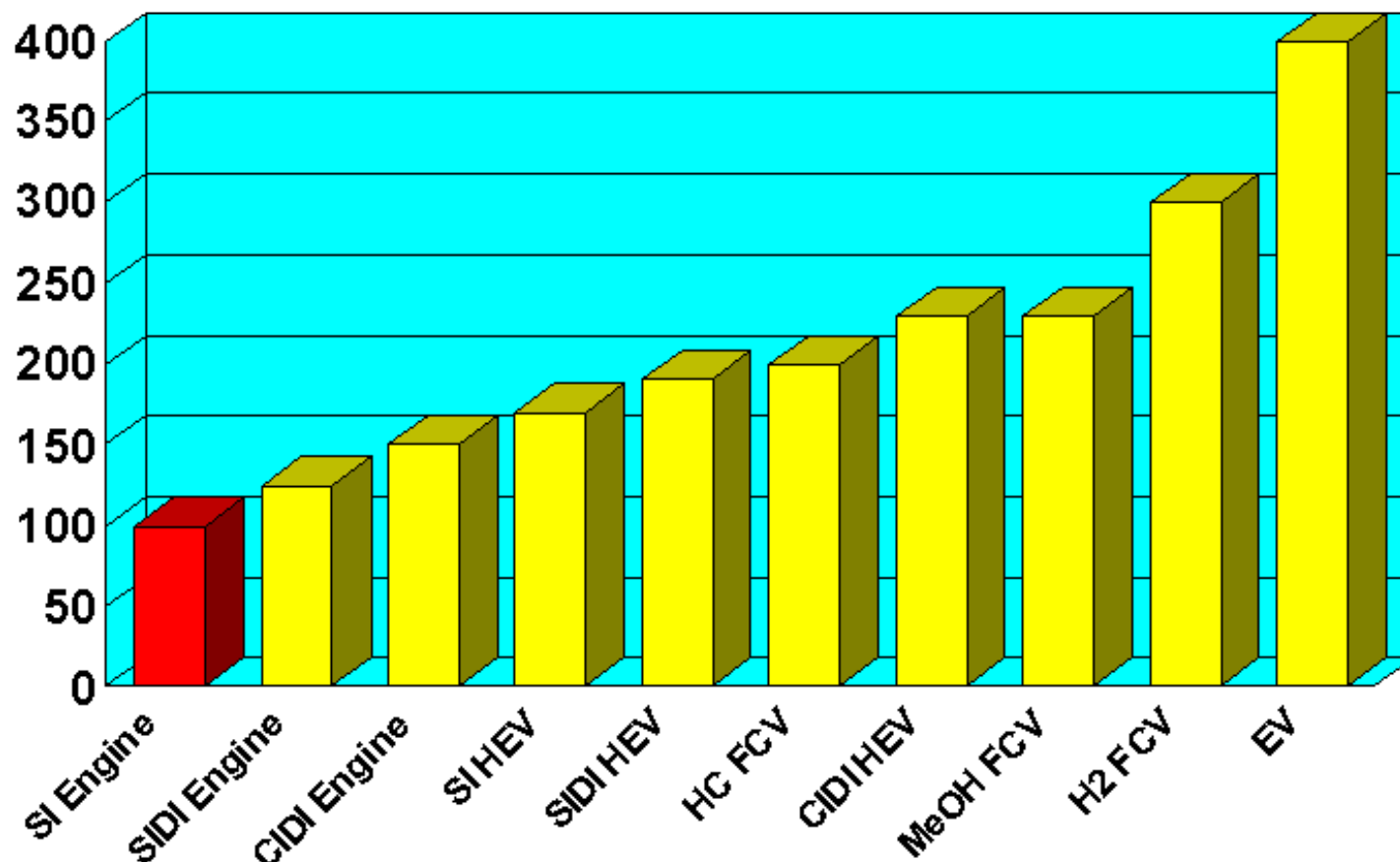


REET1.5a Includes Eighteen Fuel Pathways for Fuel-Cell Vehicles





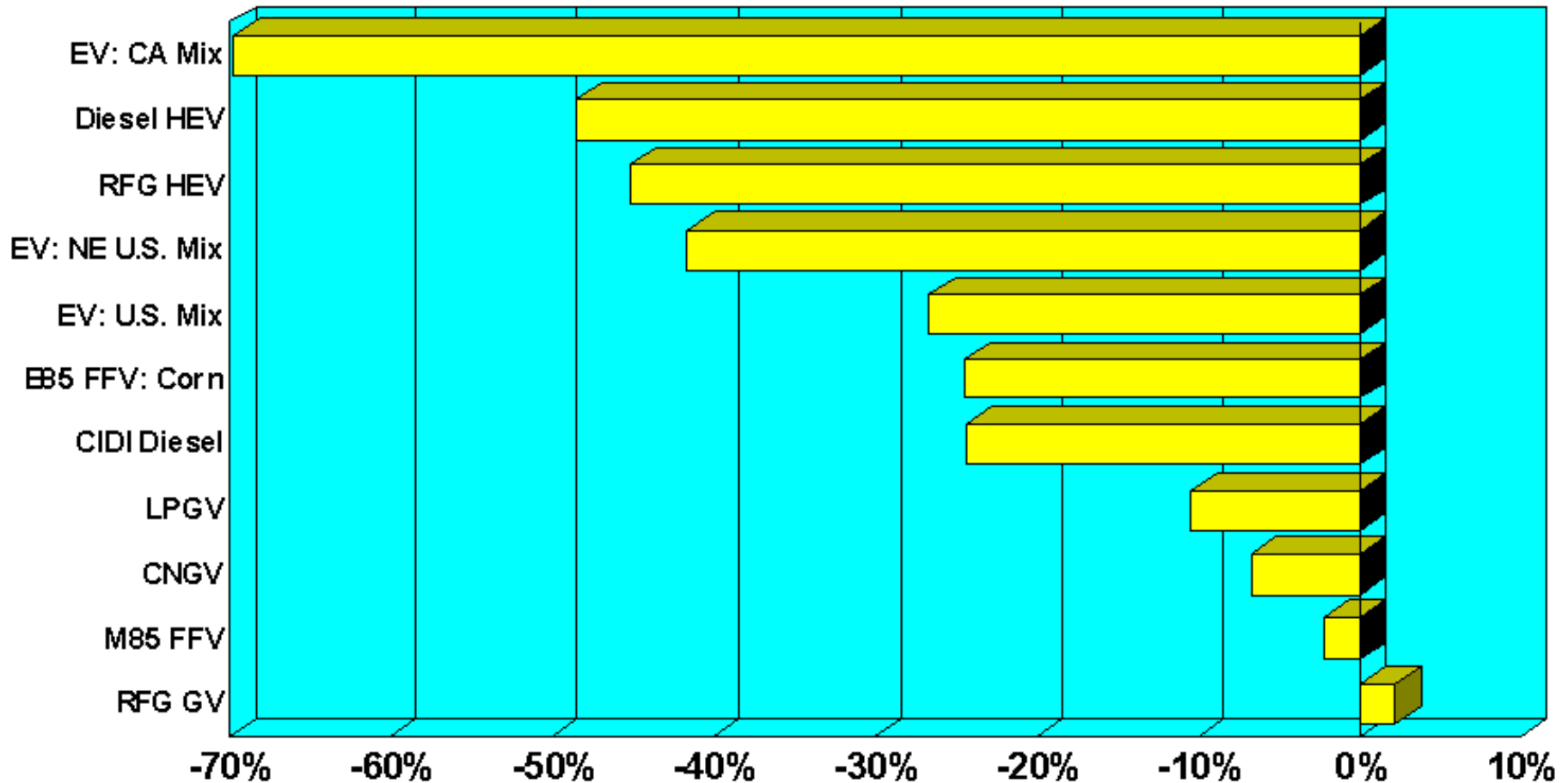
Relative Fuel Economy of Vehicle Propulsion Systems (Tanks to Wheels)



Note: Based on gasoline-equivalent fuel economy and for technologies to be available around 2010.

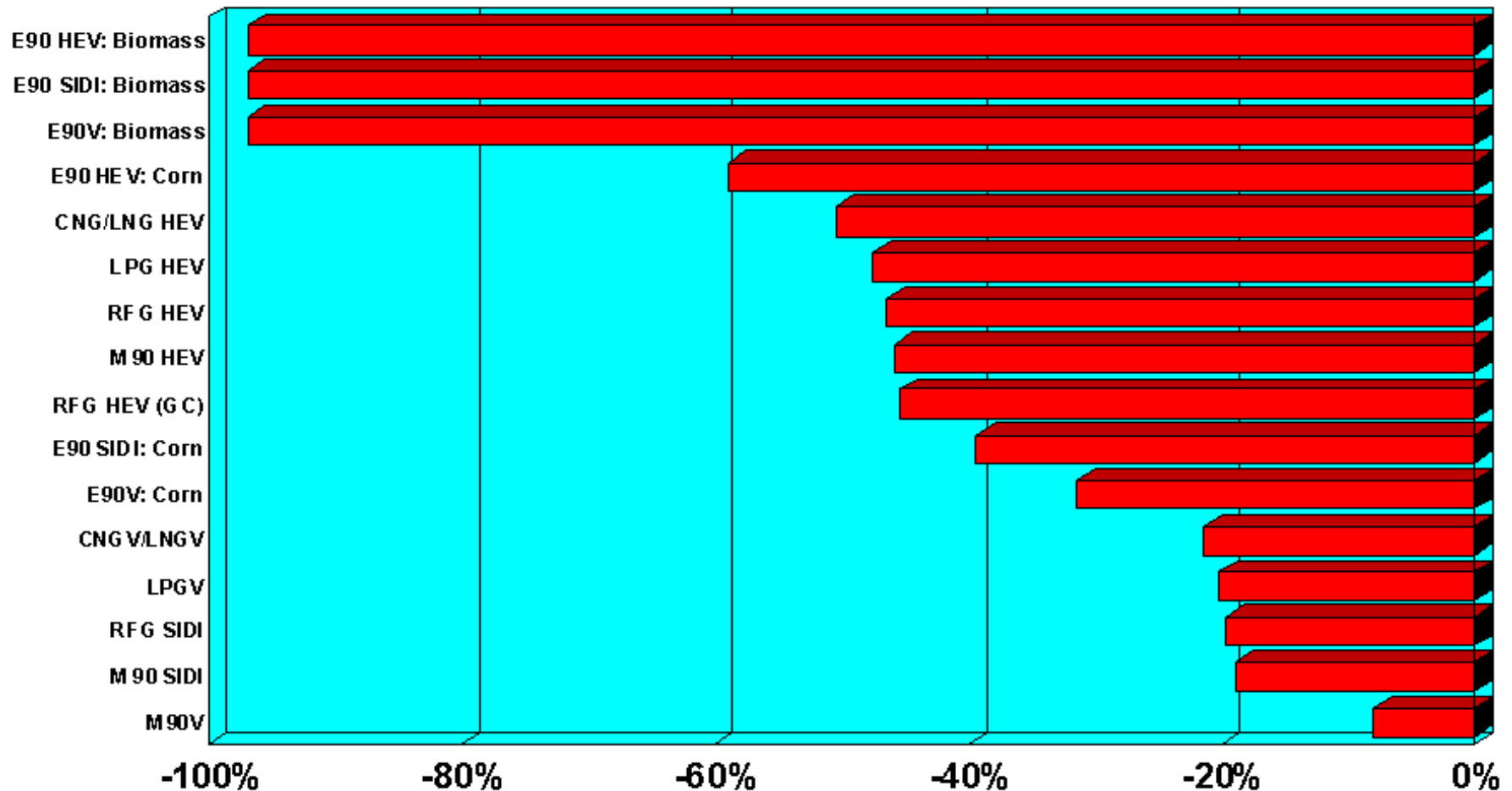


Fuel-Cycle GHG Emission Changes: Near-Term Technologies (Relative to CG GV)



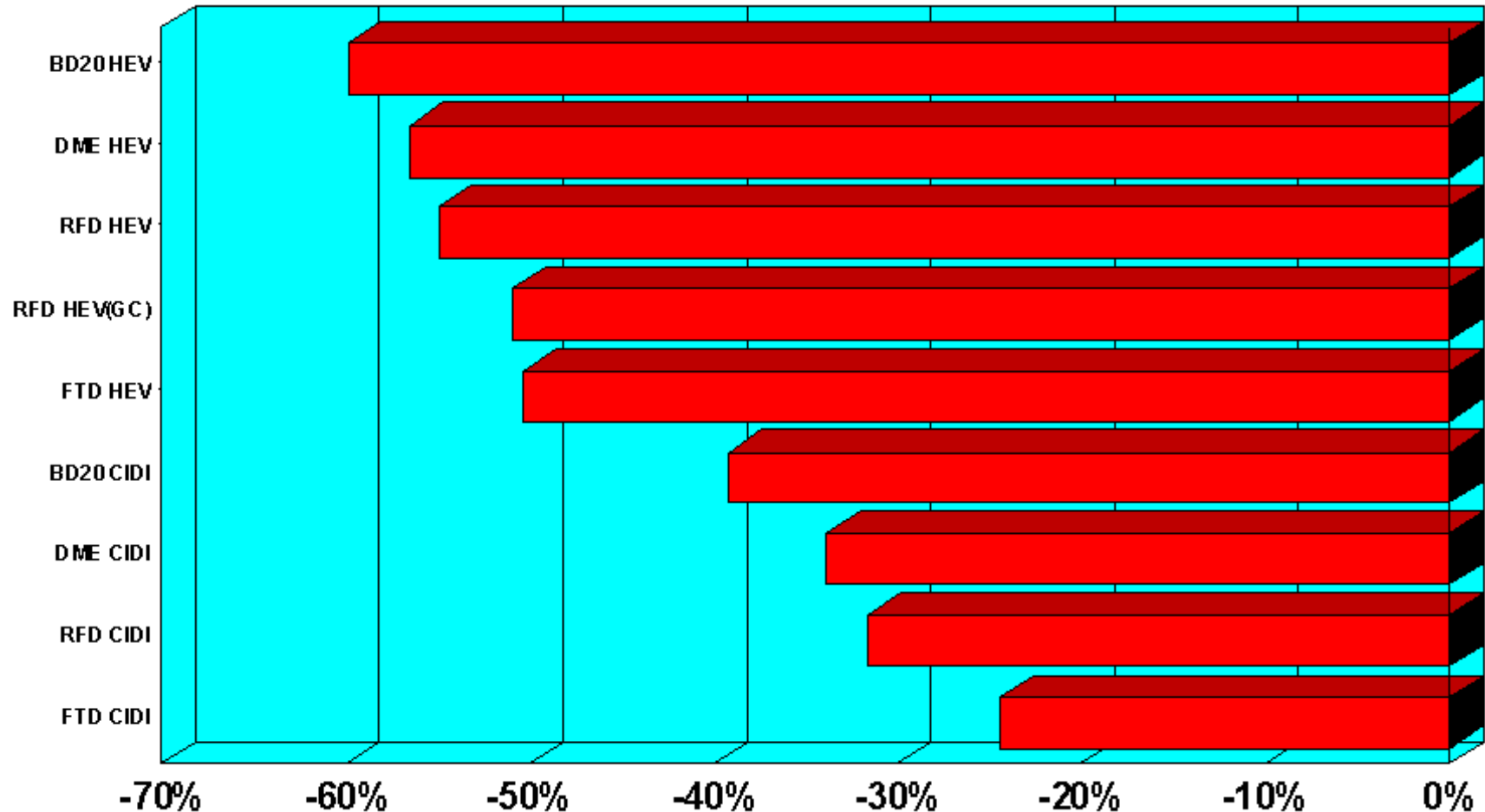


Fuel-Cycle GHG Emission Changes: Long-Term SI and SIDI Technologies (Relative to RFG GV)



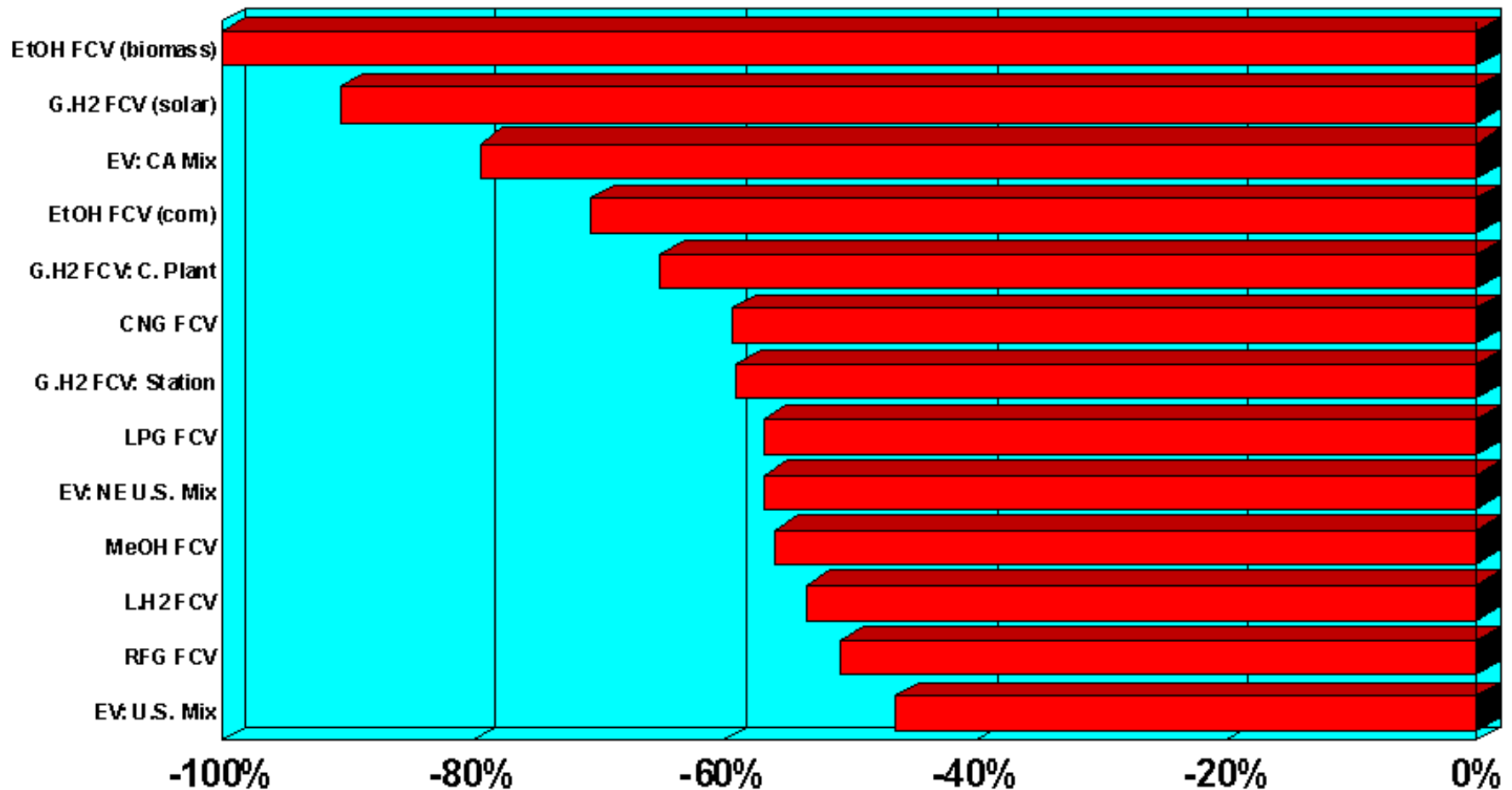


Fuel-Cycle GHG Emission Changes: Long-Term CIDI Technologies (Relative to RFG GV)





Fuel-Cycle GHG Emission Changes: Long-Term EVs and FCVs (Relative to RFG GV)





Summary: GHG Emission Impacts

- Near-term technologies offer limited GHG emission reduction benefits, but they can bring reductions now
- Long-term, advanced technologies offer great GHG emission reduction benefits. However, some of them face market hurdles, and others are in the R&D stage
- Switch of transportation fuels from fossil fuels to renewable fuels results in huge GHG emission reduction benefits
- Among the vehicle technologies included in GREET, there are trade-offs among fuel economy, GHG emissions, and criteria pollutant emissions



GREET 1.5a Computer Hardware and Software Requirements

- GREET1.5a is about 2.8 MB of size
- Is developed for personal computer applications
- Requires Windows95 or higher version of PC operating system
- Is developed in MS Excel97 and requires Excel 97 or higher version



Several Documents Have Been Prepared for GREET and Are Available from ANL Transportation Web Site

- GREET1.5 – Transportation Fuel –Cycle Model Volume 1: Methodology, Development, Use, and Results. ANL/ESD-39 Aug., 1999
- A Full Fuel-Cycle Analysis of Energy and Emissions Impacts of Transportation Fuels Produced from Natural Gas, ANL/ESD-40, Dec. 1999
- The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, Version 1.5, memo prepared in Aug. 1999
- GREET1.5a: Changes from GREET1.5, memo prepared in Jan. 2000



Key Issues in GREET Simulations and Results

- Vehicle and fuel production technologies are continuously evolving
- GREET's key assumptions are continuously being revised
- Ways of addressing uncertainties in GREET simulations are being explored now
- Where should the simulation boundary be drawn?



A New Draft GREET Version Was Created to Model Fuel Transportation in Detail

- Five modes are included for transporting feedstocks and fuels: ocean tankers, barges, rail cars, pipelines, and trucks
- Carrying capacity and corresponding fuel consumption rate are determined for each mode to transport a given fuel
- Distance from an origin to a destination is specified for transporting a given feedstock or fuel
- With the above information, GREET calculates energy use and emissions for transporting a unit of feedstock or fuel
- This expansion will be finalized in a new GREET version



GREET model and documents are available at: www.transportation.anl.gov/ttrdc/greet/

TTRDC - Argonne Transportation - GREET Model - Microsoft Internet Explorer provided by MSN

File Edit View Favorites Tools Help

Address <http://www.transportation.anl.gov/ttrdc/greet/> Go

ARGONNE NATIONAL LABORATORY
TRANSPORTATION
TECHNOLOGY R&D CENTER

Site Map | Home
Research Programs | Publications

Research Programs

TECHNOLOGY ASSESSMENTS

The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model

For a given transportation fuel/technology combination, GREET 1.5 separately calculates:

1. fuel-cycle consumption of
 - o total energy (all energy sources),
 - o fossil fuels (petroleum, natural gas, and coal), and
 - o petroleum,
2. fuel-cycle emissions of greenhouse gases — primarily carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O); and
3. fuel-cycle emissions of five criteria pollutants — volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter with a diameter measuring 10 micrometers or less (PM₁₀), and sulfur oxides (SO_x).

The model is designed to readily allow researchers to input their own assumptions and generate fuel-cycle energy and emission results for specific fuel/technology combinations.

Download GREET Model

NOTE: Please read the following copyright/license terms and memo before downloading the GREET model. These documents contain essential information about using the model.

- [Copyright and License Terms and Conditions](#)
- [GREET 1.5a: Changes from GREET1.5](#) [160kb pdf - added 2/22/00]